Docket 3123-509

Marked-Up Version of Substitute Specification Under 37 C.F.R. 1.125

Method and Apparatus for Runout Correction

During Self-Servo Writing

By

Thomas Melrose

and

James Hargarten

Related Application

This application claims p~~P~~riority ~~is claimed~~ from U.S. Provisional Patent Application Serial No. 60/403,583, filed on August 14, 2002, entitled "On~~N~~ the~~THE~~ Fly~~LY~~ SSW ERC," ~~, filed on August 14, 2002,~~ which is incorporated herein by reference in its entirety.

Field of the Invention

The present invention relates to disk drives~~self-servo writing disk drives~~ and, more particularly, to ~~runout correction while~~ disk drive self-servo writing and runout correction ~~disk drives~~.

Background of the Invention

~~Background for the present invention is provided herein in connection with a disk drive system. It should be noted, however, that the present invention is not intended to be limited to such systems.~~

A disk drive is a data storage device that stores digital data in tracks on the surface of a data storage disk. Data is read from~~,~~ or written to~~,~~ a track ~~of the disk~~ using a transducer that is held close to the track while the disk spins about its center at a substantially constant angular velocity. To properly locate the transducer near the desired track during a read or write operation, a closed-loop servo control system~~scheme~~ read~~is generally implemented that use~~s a servo pattern~~data read~~ from the disk surface to generate a position error signal (PES) and align the transducer with the desired track.

The servo ~~data includes servo~~ patterns ~~that~~ typically includes~~comprise~~ short servo bursts of a constant frequency signal. The servo bursts~~, which~~ are written in a servo sector on the track, are very precisely located and are offset from either side of the~~a~~ ~~data~~ track~~'s~~ centerline. The servo bursts ~~are written in a sector header area, and~~ can be used to find the track centerline~~ of a track~~. Keeping the transducer~~Staying~~ on-center is required during both reading and writing to and from the track. These servo burst~~-data area~~s allow the~~a~~ transducer~~head~~ to follow the~~a~~ track centerline around the~~a~~ disk~~,~~ even when the track is perturbed (out-of-round)~~, as can occur~~ due to~~with~~ spindle wobble, disk slip and/or thermal expansion.

Servo bursts are conventionally written on the~~a~~ disk in the disk drive by a dedicated, external servo track writer (STW). The STW~~, which~~ typically ~~involves the~~ uses a~~of~~ large granite blocks to support the disk drive and reduce~~quiet~~ outside vibration~~ effects~~. Unfortunately, the STW is ~~servo track writers are~~ expensive~~,~~ and requires a clean room ~~environment~~since~~, as~~ the disk and the transducer~~heads~~ are exposed to ~~the environment to~~ allow ~~the~~ access by~~of~~ the STW~~servo track writer's external head and actuator~~.

D~~Accordingly,~~isk drives have been developed that use self-servo writing (SSW) ~~methods~~ for writing the~~a~~ servo~~-~~ pattern~~ with a disk drive's own transducers have been utilized~~.

~~Typically in a~~ SSW typically uses~~process,~~ a temporary ~~set of~~ pre-existing servo reference pattern~~servo information~~ on the~~a~~ disk ~~is used~~ to position~~control~~ the transducer ~~position~~ while the ~~final~~ servo bursts are written to the disk~~(s) in the disk drive~~. ~~The~~ SSW ~~process~~ involves ~~a combination of~~ three largely distinct step~~ub-processes, including~~: (1) reading the reference pattern~~temporary servo information~~ to provide precise timing, (2) positioning the~~a~~ transducer at a sequence of radial positions using amplitude ~~the~~ variations in a read-back signal ~~amplitude~~ from the reference pattern as a sensitive position indicator, and (3) writing the ~~final~~ servo burst~~-pattern~~s at the times and radial positions defined by the first~~other~~ two step~~processes,~~ to form concentric circular tracks. ~~An example~~ SSW ~~process~~ is described in U.S. Patent No. 5,907,447 to Yarmchuk~~,~~ et al. ~~Other~~ SSW can also involve ~~processes are possible, such as~~ servo~~-~~propagation where the servo reader-to-writer offset ~~is used to~~ allows servoing on written ~~one set of~~ servo bursts while writing ~~an~~other servo bursts.

In an ideal disk drive~~ system~~, the tracks ~~of the data disk~~ are non-perturbed circles ~~that are~~ situated about the center of the disk. T~~As such, each of t~~hese ideal tracks includes a track centerline that is located at a known constant radius from the disk center. In an actual system, however, it is difficult to write non-perturbed circular tracks to the ~~data storage~~ disk. V~~That is, problems, such as v~~ibration, bearing defects, etc. can result in tracks that are written differently from the ideal non-perturbed circular track shape. Positioning errors created by the perturbed nature of these tracks are known as written-in repeatable~~repetitive~~ runout (~~S~~SW_RRO).

—The perturbed shape of these tracks complicates the transducer positioning ~~function~~ during read and write operations performed after ~~the~~ SSW ~~process,~~ because the servo control system needs to continuously reposition the transducer during track following to keep up with the constant changing radius of the track centerline with respect to the center of the spinning disk. Furthermore, the perturbed shape of these tracks can result in ~~problems such as~~ track squeeze and track misregistration errors during read and write operations.

Disk drives have been developed that ~~In certain systems, as will be understood by those skilled in the art, after all the servo patterns for all tracks are written, an additional process is used to directly~~ measure the ~~S~~SW_RRO for each track, generate compensation values (also known as embedded runout correction values or ERC values) and write the ERC values to servo sectors in the tracks ~~of a disk so that compensation values are generated and written in servo fields on the disk~~. Thereafter, during read/write operations, the ERC~~compensation~~ values are used to position the transducer along an ideal track centerline.

This~~An example of such a process~~ is described in U.S. Patent No. 6,549,362 to Melrose~~,~~ et al. (the '362 patent), which is incorporated herein by reference.

Although the ERC values correct or reduce the WRRO, generating the ERC values~~such a correction technique is effective, it~~ can be time consuming. After ~~the~~ SSW ~~process is completed~~, the ~~amount of SS~~W-RRO ~~present~~ on each track is ~~of a disk must be~~ measured~~,~~ and then the ERC values are calculated~~a calculation is performed to determine correction factors to minimize the SSW-RRO in each track~~. Finally, the ERC values~~correction factors~~ are~~must be~~ written to ~~the disk in~~ each servo sector~~field~~ of each track. This ~~process~~ requires several revolutions of the disk to measure the ~~S~~SW-RRO on the track and then more revolutions of the disk to write the ERC values~~correction factors~~ to the track~~disk~~. In one example, this ~~such a process~~ may require 12 or more revolutions of the disk to determine~~,~~ and write~~,~~ the ERC values~~correction factors~~ for each track.

There is, therefore, a need for ~~a more efficient method and apparatus for improving embedded runout correction in~~ a disk drive that performs SSW and ~~during the self-servo writing process, while~~ reduces~~ing~~ the ~~correction~~ time required to provide ERC values.

Brief Summary of the Invention

The present invention addresses the above needs. T~~In one embodiment, t~~he present invention provides a disk drive that determines WRRO during ~~method and system for self-writing track locations of a storage surface of a data disk of a disk drive, wherein the runout in the write tracks is determined during the self-servo writing (~~SSW~~) process~~. ERC~~Runout~~

~~correction~~ values are calculated and then ~~(immediately)~~ written into corresponding servo sectors~~RRO fields in the write position~~ during ~~the~~ SSW ~~process~~.

The disk drive can include a disk that includes a reference pattern which provides position information for self-writing servo bursts such that a PES is based on the reference pattern and the ERC values for the servo bursts are based on the PES.

The disk drive can also include a controller which implements the SSW of the present invention.

A~~An example~~ method ~~of such a self-servo-writing method according to the present invention~~ includes determining a first PES that indicates WRRO for first servo bursts using a transducer to read the reference pattern, ~~the steps of:~~ self-writing the first servo bursts ~~along a circular track~~ using~~via~~ the~~a~~ transducer~~, and determining a first position error signal indicating repeatable runout due to mis-positioning of said first servo bursts,~~ calculating an ERC ~~runout correction~~ value for the first servo bursts based on the first PES~~position error signal~~, ~~and~~ storing the ERC~~runout correction~~ value ~~for the first servo bursts~~ in a corresponding servo sector, and then ~~while~~ self-writing other servo burst~~track locations~~s.

T~~In one implementation,~~ he method can ~~self-writing servo bursts further~~ includes determining a second PES that indicates WRRO for second servo bursts using the transducer to read the reference pattern, ~~the steps of~~ self-writing the second servo bursts ~~along the track~~ using~~via~~ the transducer~~, and determining a second position error signal indicating repeatable~~

~~runout due to mis-positioning of said second servo bursts,~~ wherein the first and second servo bursts ~~form servo sector patterns that~~ define a~~the~~ track centerline, and calculating ~~. Then,~~ the ERC~~runout correction~~ value for the first and second servo bursts ~~is calculated~~ based on the first and second PES'~~position error signals, and stored in a corresponding servo sector while self-writing track locations~~.

In one embodiment~~example~~, each servo sector ~~pattern~~ includes a trimmed burst pattern, and ~~wherein~~ self-writing the~~said~~ first servo bursts in each servo sector ~~pattern further~~ includes ~~the steps of~~ writing two first servo bursts such that one ~~of the~~ first servo burst~~s~~ trims the other first servo burst, thereby defining a first burst seam. In that case, the first PES~~position error signal~~ indicates WRRO~~repeatable runout~~ for ~~due to mis-positioning of~~ the first burst seam. Further, self-writing the~~said~~ second servo bursts in each servo sector ~~pattern further~~ includes ~~the steps of~~ writing two second servo bursts such that one ~~of the~~ second servo burst~~s~~ trims the other second servo burst, thereby defining a second burst seam. In that case, the second PES~~position error signal~~ indicates WRRO~~repeatable runout~~ for~~due to mis-positioning of~~ the second burst seam. E~~For example, e~~ach servo sector ~~pattern~~ can include a trimmed burst pattern comprising four radially offset, circumferentially staggered~~,~~ servo bursts. Alternatively, each servo sector ~~pattern~~ can include an un-trimmed burst pattern.

In another embodiment, determining the first PES and~~position error signal further includes the step of determining a first instantaneous position error signal indicating said repeatable runout while~~ self-writing the first servo bursts occurs during a first revolution of the disk, ~~. Further,~~ determining the second PES~~position error signal~~ and ~~includes the step of~~

~~determining a second instantaneous position error signal indicating said repeatable runout while~~ self-writing the second servo bursts occurs during a second revolution of the disk, and writing the ERC value to the servo sector occurs during a third revolution of the disk. ~~One implementation involves recording the first and second instantaneous position error signals obtained while self-writing the first servo bursts, and then calculating the runout correction value using the recorded first and second instantaneous position error signals.~~

~~Further, the data disk can include a reference pattern which provides position information for self-writing the servo bursts, such that the first and second position error signals are generated based on the position information from the reference pattern.~~

~~In another aspect, the present invention provides a disk drive including a controller which implements the self-servo writing method of the present invention.~~

Other objects, features, embodiments and advantages of the invention will be apparent from the following specification taken in conjunction with the following drawings.

Brief Description of the Drawings

FIG. 1 is a diagrammatic representation of a top view of a hard disk drive~~,~~ with the top cover removed;

FIG. 2 is a diagrammatic representation of a magnetic storage disk having a data track that is compensated for runout in accordance with the present invention;

FIG. 3 is a diagrammatic representation of a servo burst pattern that may be used to position a transducer ~~head~~ with respect to a track centerline;

FIG. 4 is a flowchart of ~~the steps of an example self-servo writing (~~SSW~~) process~~ according to ~~an embodiment of~~ the present invention;

FIGS. 5A-1 and 5A-2 together form ~~is~~ a diagrammatic representation of a servo burst pattern written according to the SSW~~self-servo writing steps~~ in FIG. 4; and~~,~~

FIGS. 5B-1 and 5B-2 together form ~~is~~ another diagrammatic representation of a servo burst pattern written according to the SSW~~self-servo writing steps~~ in FIG. 4.

Detailed Description of the Invention

While this invention is susceptible of embodiments in many different forms, there are shown in the drawings and will herein be described in detail, preferred embodiments of the invention with the understanding that the present disclosure is to be considered as an exemplification of the principles of the invention and is not intended to limit the broad aspects of the invention to the embodiments illustrated.

Further, although in the description below, example embodiments of the present invention are described in connection with a disk drive ~~system~~, it should be noted~~, however,~~ that the present invention is not intended to be limited to such systems.

FIG. 1 illustrates a typical computer disk drive. The disk drive~~, generally identified by reference number~~ 100~~,~~ includes a base 104 and a magnetic disk~~s~~ (or disks) 108 (only one of which is shown in FIG. 1). The ~~magnetic~~ disks 108 is~~are~~ interconnected to the base 104

by a spindle motor (not shown) mounted within or beneath the hub 112~~,~~ such that the disks 108 can be rotated relative to the base 104. Actuator arm assembly (or assemblies) 116 (only one of which is shown in FIG. 1) is~~are~~ interconnected to the base 104 by a bearing 120. The actuator arm assembly~~ies~~ 116 ~~each~~ includes a transducer (or head) ~~head~~ 124 (which includes both a read element and a write element) at an ~~first~~ end~~,~~ to transfer data to and from a ~~address each of the~~ surfaces of the ~~magnetic~~ disks 108. A voice coil motor (VCM) 128 pivots the actuator arm assembly~~ies~~ 116 about the bearing 120 to radially position the transducer ~~heads~~ 124 with respect to the ~~magnetic~~ disks 108. By changing the radial position of the transducer ~~heads~~ 124 with respect to the ~~magnetic~~ disks 108, the transducer ~~heads~~ 124 can access different ~~data~~ tracks ~~or cylinders~~ 132 on the ~~magnetic~~ disks 108. The VCM~~voice coil motor~~ 128 is operated by a controller 136 that is in turn operatively connected to a host computer (not shown). A channel 140 processes information read from the ~~magnetic~~ disks 108 by the transducer ~~heads~~ 124.

As illustrated in FIG. 2, the disk 108 is substantially circular in shape and includes a center point 200~~located in the center of the disk 108~~. The disk 108 also includes ~~a plurality of~~ tracks 132 (only one of which is illustrated in FIG. 2) on an upper surface 204 of the disk 108 for storing ~~the~~ digital data. The ~~data~~ tracks 132 are divided into data fields 208a-208d and servo sectors (or hard sectors) 212a-212d. Generally, the data fields 208a-208d are used for storing user data as a series of magnetic transitions, while the servo sectors 212a-212d are used for storing servo information, also as a series of magnetic transitions/bursts, that ~~is used to~~ provide the transducer ~~head~~ 124 with positioning information. In particular, the servo sectors 212a-212d provide the transducer ~~heads~~ 124 with information concerning

its~~their~~ position over the ~~magnetic~~ disk 108. More particularly, the servo sectors 212a-212d provide information to the transducer ~~heads~~ 124 concerning the identity of the track 132 and the servo sector 212 over which the~~each~~ transducer ~~head~~ 124 is flying, and concerning the position of the~~each~~ transducer 124~~head~~ with respect to the centerline of the track 132.

Although the ~~magnetic~~ disk 108 illustrated in FIG. 2 has~~is illustrated as having~~ a relatively small number of data tracks 132 and servo sectors 212, it can be appreciated that a typical ~~computer~~ disk drive contains a very large number of data tracks 132 and servo sectors 212. For example, ~~computer~~ disk drives having over 100,000 tracks per inch and 240 servo sectors per track are presently available.

The disk drive 100 includes a servo control system 144 for controlling the position of the~~a~~ transducer ~~head~~ 124 with respect to the~~a~~ track 132 being followed. In general, the servo control system 144 comprises the transducer ~~head~~ 124 being positioned, which reads the position information from the servo sectors 212,~~;~~ the actuator arm assembly 116 that is carrying the transducer ~~head~~ 124,~~;~~ the VCM~~voice coil motor~~ 128, the controller 136 and~~;~~ the channel 140~~; and the controller 136~~. As described in the '362 patent, the response of the servo control system 144 to a given input is given by the error transfer function of the servo control system 144.

The track 132 is ideally non-perturbed and ideally shares a common center 200 with the disk 108, such as the ideal track 216 illustrated in FIG. 2. Due to system imperfections, however, the actual written track 132 can be perturbed, such as the non-ideal track 132

illustrated in FIG. 2, as compared to the~~an~~ ideal track 216~~ such as non-ideal track 132 as illustrated in FIG. 2~~. A perturbed or non-ideal track 132 is difficult for the~~a~~ transducer ~~head~~ 124 to follow~~;~~ because the position of the transducer ~~head~~ 124 must constantly be adjusted by the servo control system 144. Perturbations from the ideal track center negatively impact track-to-track spacing. Consequently, track-to-track spacing must be increased to compensate for this position error, leading to lower disk capacity. Further, positioning of the transducer ~~head~~ 124 is not as accurate on the perturbed~~written~~ track 132 as it would be on the~~an~~ ideal track 216.

The perturbations in the ~~written~~ track 132 due to positioning errors can be effectively reduced by SSW~~a self-servo writing process~~ according to the present invention. T~~In one embodiment, t~~he present invention provides a method and system that allows self-servo writing servo information (e.g., servo bursts) in the tracks 132 along with correction information (e.g., ERC values) that compensate for position errors (e.g., S~~S~~W-RRO). As ~~such, a~~fter ~~the~~ SSW~~ process~~, during the disk drive 100 operation~~s and by using the correction information~~, the~~a~~ transducer ~~head~~ 124 servoing on the~~a~~ track 132 can more closely follow the path of the~~an~~ ideal track~~, such as the path of track~~ 216 using the correction information.

T~~As mentioned above, t~~he tracks 132 ~~on the disk 108~~ are each divided into interleaving ~~a plurality of~~ data fields 208 and servo sectors ~~or hard sectors~~ 212. The servo sectors 212 are located in servo wedges that radially extend across the tracks 132. The servo sectors 212 include, among other things, information for use by the disk drive 100 in

locating the~~a~~ transducer ~~head~~ 124 above a desired track 132~~ of the disk 108~~. When a host computer requests that data be read from or written to a particular ~~track 132 and~~ data field 208 in a particular track 132~~of the disk 108~~, the transducer ~~head~~ 124 must be moved to the track 132 and then must be positioned at a predetermined location relative to the centerline of the track 132 before the data transfer can take place. For purposes of illustrating the present invention, it will be assumed that the transducer 124 should be placed on the track centerline in order to read from and write to the disk 108. It should be understood that the invention is not limited to solely reading and writing when the transducer 124 is placed at the track centerline. T~~As noted above, t~~he track 132 is written to the disk 108 during~~in a~~ SSW ~~process~~ according to the present invention such that ~~SS~~W_RRO is effectively reduced.

FIG. 3 illustrates typical servo pattern ~~hard sectors~~ 130b~~a,~~ stored within ~~the servo portion of~~ a servo wedge 130a. The servo pattern 130b is used ~~sector 212~~ for ~~use in~~ centering the~~a~~ transducer ~~head~~ 124 on a desired track 132. In FIG. 3, the tracks 132 are diagrammatically laid out linearly in a down-track (circumferential) direction from left to right, and in a cross-track (radial) direction from top to bottom. Three tracks 132 designated as tracks Tn-1, Tn and Tn+1 are shown. -The~~In this example, a~~ servo pattern~~hard sector 130a includes sets~~ 130b includes~~of~~ radially offset, circumferentially staggered, final -servo bursts 130c~~,~~ designated as A, B, C and D bursts~~ A, B, C and D~~. —The servo bursts 130c define the centerlines 132a ~~Tn-1, Tn and Tn+1~~ of the tracks 132~~ of the disk 108~~. ~~In FIG. 3, the tracks 132 are diagrammatically laid out linearly in down track direction from left to right, and in cross track direction from top to bottom, of the page.~~ Thus, t~~T~~hree ~~example~~ centerlines 132a~~Tn-1, Tn and Tn+1~~ of three tracks 132 are defined by the servo bursts 130c

~~on each track~~. The servo bursts 130c provide analog information to the servo control system 144 for positioning the transducer 124~~/head positioning~~. Other numbers of servo bursts and offset configurations are also possible. In this~~e~~ example~~ herein~~, the A, B bursts form a burst pair and the C, D bursts form another burst pair. During normal operation of the disk drive 100~~operations~~, ~~all of~~ the ~~four bursts~~ A, B, C and D bursts are used by the servo control system 144 to position ~~when~~ the transducer 124 ~~is positioned~~ at a ~~write~~ track centerline.

~~An example~~ SSW ~~process according to the present invention for writing~~ a ~~servo~~ track 132 that is later sampled by the servo control system 144 in positioning the transducer~~head~~ 124 to follow a track 132 which more closely resembles the ideal track 216~~,~~ is now ~~generally~~ described. A temporary reference pattern of servo information (not shown) is initially provided on the disk 108 and ~~is~~ used by the servo control system 144 to determine a ~~position error signal (~~PES~~)~~ for positioning the transducer 124 to write the servo bursts 130c. In a preferred implementation~~ of the SSW process,~~, an iterative process such as described in the '362 patent is applied to the ~~temporary~~ reference pattern to ~~that is used for servoing while writing the final servo bursts A, B, C and D. This~~ reduces the RRO ~~that may have been~~ written into the reference~~temporary servo~~ pattern~~ itself~~. The reference~~temporary servo~~ pattern~~,~~ with reduced RRO~~,~~ is then used for writing the servo bursts 130c.

The ~~The example~~ SSW ~~process~~ described herein generates~~is in conjunction with a~~ "trimmed" servo burst-s~~ystem~~. ~~However, as those skilled in the art will appreciate, the present invention is useful with untrimmed, and other trimmed, servo burst systems.~~ As ~~used herein, a~~ trimmed servo burst has~~is one in which~~ a circumferential~~radial~~ edge (a top or bottom edge that extends in the circumferential direction) that ~~of the burst~~ is DC erased

during a subsequent pass of the write element of the transducer 124 at a displaced radial position relative to the disk 108. The~~A~~ burst is trimmed to have e.g. a bottom~~lower radial~~ edge ~~to be~~ in radial alignment with a top~~the upper radial~~ edge of an adjacent burst. It is possible to trim a previously written burst during a single pass of the transducer 124 write element~~head~~ along a servo-writing path for writing another burst. However, the present invention is useful with untrimmed, and other trimmed, servo bursts. -A discussion of trimmed and untrimmed bursts is provided in U.S. Patent No. 6,519,107 to Ehrlich~~,~~ et al., which is incorporated herein by reference.

The SSW ~~process~~ includes reading the reference pattern using the transducer 124 to generate a PES, calculating an ERC value based on the PES, ~~the steps of~~ self-writing the servo bursts 130c along a track 132 using~~via~~ the~~a~~ transducer 124, ~~calculating repeatable runout correction values based on instantaneous position error values when writing the servo bursts,~~ and writing the ERC~~correction~~ values to the corresponding RRO fields 133 ~~(RRO fields)~~ on the track 132 using the transducer 124. As such, the centerline of a mis-positioned ~~data~~ track 132 is effectively moved (repositioned) to a corrected track centerline location. After the SSW ~~process~~ is completed, during ~~disk drive~~ operation of the disk drive 100, initially upon seeking to a ~~data~~ track 132 and reading a first set of the servo bursts 130c, the servo control system 144 follows the original (uncorrected) track centerline until it reads the ERC~~correction~~ values from the corresponding RRO field 133, and thereafter moves the transducer~~head~~ 124 to the corrected track centerline location. Thereafter, the servo bursts 130c and the ERC~~correction~~ values in the corresponding RRO fields 133 are used by the

servo control system 144 to continue following the corrected (effectively re-positioned) track centerline.

I~~As such, i~~n one example, in self-writing a track 132, the transducer 124 is positioned to write the ~~bursts A ("~~A bursts~~")~~ along a circular path during a revolution of the disk 108. Then, in another revolution of the disk 108 the transducer is moved to write the ~~bursts C ("~~C bursts~~") are written~~. Then, in another revolution of the disk 108 the transducer 124 is moved to write the ~~bursts B ("~~B bursts~~")~~, and~~wherein~~ the B bursts ~~B~~ trim off the bottom edges of the A bursts ~~A~~, thereby defining ~~a~~ first burst seams (transitions) 130d between the A bursts and the B bursts. In addition, t~~T~~he positioning errors in ~~when writing~~ the burst seams 130d~~, which~~ are measured by the transducer 124 reading the reference pattern ~~while the servo system is self-writing the B bursts,~~ and are stored in memory during the revolution of the disk 108. Then~~Finally~~, in another revolution of the disk 108, the transducer 124 is moved to write the ~~bursts D ("~~D bursts~~") are written~~, and~~wherein~~ the D bursts ~~D~~ trim off the bottom edges of the C bursts ~~C~~, thereby defining a second burst seam (transition) 130e between the C, D bursts. In addition, t~~The~~he positioning errors in ~~when writing~~ the burst seams 130e~~, which~~ are measured by the transducer 124 reading the reference pattern ~~while the servo system is self-writing the D bursts,~~ and are ~~also~~ stored in memory during the revolution of the disk 108.- Then, ~~for example,~~ the ~~first and second~~ positioning errors for the A, B bursts and the C, D bursts are used to generate ERC~~correction~~ values that are written by the transducer 124 to the RRO fields 133 corresponding to the ~~four servo bursts~~ A, B, C and D bursts of the track 132 during another revolution of the disk 108~~Tn-1 in FIG. 3~~.

Other sequences for writing and trimming the servo bursts 130c are possible. The motion of the transducer~~head~~ 124 defines where the burst seams 130d,~~ and~~ 130e occur. Since the transducer 124 has ~~As there is head~~ motion due to ~~disturbances that cause~~ non-repeatable runout ~~disturbances~~ (NRRO), the difference between the intended position of the burst seams 130d, 130e and the actual position of the burst seams 130d, 130e~~,~~ due to such ~~head~~ movement of the transducer 124~~,~~ is a capture of the NRRO~~,~~ and is recorded in the servo burst~~ pair patterns~~ 130c by mis-positioning ~~of~~ the burst seams 130d,~~ and~~ 130e as ~~(S~~SW-RRO~~)~~. T~~According to the example described herein, t~~o compensate for the ~~S~~SW-RRO in the burst seams 130d,~~ and~~ 130e, the ERC~~correction~~ values are determined and written to the RRO fields 133~~ as described, to compensate for the mis-positioning of the seams 130d and 130e~~. For example, if the burst seam 130e ~~(and/or seam 130d)~~ is located too far ~~off~~ towards the outer diameter (OD) of the disk 108 (offset from ideal) by a given~~certain~~ amount~~ (offset from ideal)~~, then the ERC~~correction~~ values are calculated and written into the corresponding RRO fields 133 during ~~the~~ SSW~~ process~~, and ~~such that~~ after ~~the~~ SSW~~ process~~, during operation of the disk drive 100~~operation~~, the servo control system 144 uses the burst seam~~ positions~~ 130d~~e~~, 130e~~d~~ and the ERC~~correction~~ values in the corresponding RRO fields 133~~,~~ to position the transducer 124 towards the inner diameter (ID) of the disk 108 by the~~said~~ given~~certain~~ amount. As~~,~~ such, ~~that~~ the servo control system 144 effectively follows a track centerline at the intended (~~e.g.,~~ ideal/circular) track position.

Specifically, after the ~~final~~ servo bursts 130c are written by~~ the~~ SSW, in normal disk drive 100 operations, the servo control system 144 senses the position of the burst seams

130d between the ~~bursts~~ A~~, and~~ B bursts~~,~~ and the burst seams 130e between the ~~bursts~~ C~~,~~ ~~and~~ D bursts~~,~~ for track following. At each read/write position, one burst seam 130d and one burst seam 130e is used. T~~, wherein~~ the servo control system 144 averages the observed position of the burst seams 130d, 130e~~,~~ and combines that average with the ERC value~~correction information~~ in the corresponding RRO field 133~~,~~ to generate the~~a~~ ~~position error signal (~~PES~~)~~ to control the VCM 128 for properly positioning the transducer 124 over the track~~s~~ 132. Therefore, if during ~~the~~ SSW ~~process~~, one or both of the burst seams 130d, 130e are~~were~~ mis-positioned slightly towards ~~e.g.~~ the ID or the OD of the disk 108, and thus slightly mispositioned slightly away from the~~of~~ intended (ideal) position, then ~~according to the present invention,~~ the ~~effect of the correction~~ ERC value in the PES ~~is to~~ compensates for that mis-positioning~~,~~ and ~~whereby~~ the transducer ~~head~~ 124 ~~is made to~~ follows the path of an ideal track 216 using the~~said~~ PES generated in each of the servo sectors 212 of the~~a~~ particular track 132.

The reference pattern is provided on the disk 108 before the SSW begins~~SSW RRO in each of the seams 130d, 130e is related to the instantaneous PES at the time the seams 130d, 130e are written (created). The instantaneous PES is determined using said pre-existing temporary servo information that is used for head positioning during the SSW process~~. A~~s noted, a~~n iterative process such as described in the '362 patent is applied to the reference pattern~~temporary servo information~~ to reduce the RRO that is~~may have been~~ written into the reference pattern~~temporary servo information itself~~. The reference pattern~~temporary servo information,~~ with reduced RRO~~,~~ is then used for writing the servo bursts 130c and calculating the ERC values.

In one example, the reference pattern~~temporary servo information~~ includes a set of circumferentially spaced spiral~~ tracks~~. The spirals ~~(each spiral~~ start~~ing~~ at the OD of the disk 108 ~~from a position on the disk OD~~ and end~~ing~~ at the ID of ~~on a position on~~ the disk 108. The ~~ID), the~~ spirals have information written along their length that provide radial positions for track following during~~in~~ SSW ~~self-writing~~ the servo bursts 130c~~A, B, C and D~~ on the~~circular~~ tracks 132.

The WRRO in the burst seams 130d, 130e is related to the PES at the time the burst seams 130d, 130e are written (created), and the PES is determined using the reference pattern.

In one case, each servo burst 130c is written a short time after the transducer 124 passes over a spiral. Because the NRRO is at a lower frequency than the spiral sample rate, the transducer 124~~head~~ cannot move too far off a ~~circular~~ track 132 after each spiral. As such, the ~~instantaneous~~ PES generated ~~value~~ at the time the transducer 124~~head~~ passes~~d~~ over and reads the last spiral before the servo burst 130c is written is a good estimate of the position error when the~~at~~ servo burst 130c i~~was~~ subsequently written. That is, the PES generated by reading the spiral indicates the PES for the servo burst 130c. As a result, the PES for the servo burst 130c is generated by reading the spiral immediately before writing the servo burst 130c, and without reading the servo burst 130c, thereby avoiding additional revolutions of the disk 108 that would otherwise be needed to read the servo burst 130c to generate the PES, and in turn reducing the overall manufacturing time. -It is preferable~~,~~ to

record (~~e.g.,~~ store in memory) the ~~instantaneous~~ PES from the transducer 124 reading the spiral ~~signal~~ at the time ~~that~~ the transducer 124 crosses the spiral, immediately before~~prior to~~ writing the servo burst~~s~~ 130c in a servo ~~hard~~ sector 212. In this~~e~~ example~~herein~~, where four servo bursts are used, the ~~instantaneous~~ PES~~-valu~~'es~~,~~ for ~~when~~ the servo bursts 130c~~were~~ written in the servo sectors 212 around a track 132~~,~~ are used to back-calculate the ERC~~correction~~ values to be written in the RRO fields 133 on the track 132. In one version, the ERC~~calculated correction~~ values are written to the corresponding RRO fields 133 around the track 132 in a ~~disk~~ revolution of the disk 108 after the servo bursts 130c are written.

If the spiral has been corrected for RRO, ~~by a process~~ such as by the process described in the '362 patent, then the PES from the spiral ~~signal~~ is equal to the mis-position of the transducer 124 from the ideal track centerline (the frequency content of the NRRO is significantly lower than the servo sample rate). This ~~measured instantaneous~~ PES from the spiral ~~signal~~ is a good indication of the mis-position of the transducer 124 as the servo burst~~s~~ 130c is~~are~~ written. It is also possible to measure ~~record~~ the ~~instantaneous~~ PES ~~signal~~ on the spirals on both sides of the servo burst~~s~~ 130c and to inter~~extra~~polate a more accurate mis-position of the servo burst~~s~~ 130c~~as they are written in the SSW process~~. That is, the ERC value can be calculated using an interpolated PES based on PES's measured from spirals on both sides of the servo burst 130c. After the PES from the spiral is generated such that~~When the servo bursts 130c have been written,~~ the induced error due to servo burst mis-positioning is determined, ~~and~~ the ERC ~~correction~~ values is calculated. Once the ERC ~~correction~~ value ~~(e.g., position error)~~ hass been calculated, the ERC value ~~it~~ can be written to the RRO fields 133~~of the servo system of the drive~~. In this example, where multiple servo bursts 130c are

used, it will be necessary to reposition the transducer 124~~head~~ to the track~~write~~ centerline before~~prior to~~ writing the ERC values~~correction~~ in the RRO fields 133 of the track 132.

An example ~~implementation of the above~~ SSW ~~process~~ is now described ~~in more detail~~. A~~In a preferred implementation of the SSW process, a~~ process such as described in the '362 patent is applied to the reference pattern~~temporary servo information~~ (e.g., spiral tracks) that is ~~are~~ used for servoing the transducer 124 as the transducer 124 ~~while~~ writes~~ing~~ the ~~final~~ servo bursts 130c~~A, B, C and D~~. -This reduces, and can virtually eliminate, the RRO ~~that may have been~~ written into the reference pattern~~temporary servo information itself~~. The reference pattern~~temporary servo information~~ with reduced RRO~~,~~ is then used for writing the servo bursts 130c and calculating the ERC values~~A, B, C and D~~. However, ~~as mentioned,~~ in writing the servo bursts 130c that define the burst seams 130d, 130e~~,~~ the NRRO is recorded as ~~S~~SW-RRO in~~as~~ mis-positioned burst seams 130d and/or 130e that perturb the track 132. The ~~instantaneous~~ PES from the reference pattern~~temporary servo information~~ immediately before ~~when~~ writing~~laying down~~ the burst seams 130d, 130e indicates how far the burst seams 130d, 130e are mis-positioned from their ideal/intended position. The ~~instantaneous~~ PES ~~(PES_RRO)~~ is obtained from the reference pattern~~temporary servo information,~~ immediately before ~~the instant~~ one servo burst 130c trims another servo burst 130c~~,~~ and is~~are~~ stored in memory.

T~~As such, t~~he ~~instantaneous~~ PES from the reference pattern immediately before ~~(PES_RRO) while~~ performing a burst write/trim operation that controls a position of a burst seam 130d, 130e~~position,~~ indicates how far the burst seams 130d, 130e is~~were~~ mis-

positioned. That is, the mis-positioning error (~~S~~SW_RRO) is the stimulus and the PES ~~_RRO~~ is the response. T~~(t~~he mis-positioning error ~~(SSW_RRO)~~ can be calculated from the ~~position error values (~~PES~~_RRO), such~~ as described in the '362 patent~~)~~.

The ERC ~~correction~~ values are calculated based on the PES from the reference pattern ~~_RRO, as described further below,~~ to compensate for mis-positioning ~~of~~ the burst seams 130d, 130~~3~~e. The ERC~~correction values~~ values are written to the RRO fields 133 during ~~the~~ SSW ~~process~~, and after ~~the~~ SSW ~~process~~ is completed, during the disk drive 100 operation~~s~~, the ERC ~~correction~~ values are read from the RRO fields 133 and combined with the corresponding servo bursts 130c position information~~,~~ to generate a ~~control signal (~~PES~~)~~ for the VCM 128 to position the transducer 124 to compensate for mis-positioning the burst seams 130d, 130~~3~~e, thereby reducing the overall track runout.

In general, the ~~instantaneous position error due to repeatable runout (~~PES ~~_RRO)~~ is derived by reading the reference pattern immediately before ~~temporary servo information when~~ the burst seams 130d, 130e are written ~~laid down~~ for a track 132~~, and then generating a position error signal therefrom~~. O~~The process of o~~btaining the PES~~position error signal/data~~ from a~~the~~ reference pattern ~~temporary servo information~~ is known by those skilled in the art, and need not be~~as such not~~ described herein. Preferably, the position error data is obtained from the reference pattern~~temporary servo information~~, and~~wherein~~ the RRO ~~that may have been recorded~~ written in the reference pattern~~temporary servo information~~ is reduced by known methods.

FIG. 4 i~~shows~~s a ~~detailed~~ flowchart of ~~the steps of self-servo writing (~~SSW~~) process~~ according to the present invention.

~~Further,~~ FIGS. 5A-1 and 5A-2 together shows a diagrammatic representation of a servo burst pattern written according to the ~~n example self servo writing (~~SSW~~) process (such as shown~~ in FIG. 4~~) according to the present invention~~. Seven~~Four~~ tracks~~,~~ 132 designated as tracks N, N+1, N+2, ~~and~~ N+3, N+4, N+5 and N+6~~,~~ are shown. T~~, wherein t~~he track centerlines are defined by the ~~servo bursts~~ A, B, C and~~,~~ D bursts in each servo wedge. Track N+1 has ~~is shown with~~ SSW positioning error, and~~such that~~ the track centerline is at an ~~the~~ incorrect location 150A rather than the correct location 150B. That is, ~~(i.e.,~~ the burst seams 130~~3~~d, 130~~3~~e in track N+1 cause the centerline of ~~the~~ track N+1 to be offset from its intended location~~)~~. According to the present invention, the ~~location of the~~ centerline for track N+1 is effectively moved to the correct location 150B~~,~~ based on an ERC value~~correction information~~ in a corresponding RRO field 133 ~~created as described below in conjunction with FIG. 5B~~.

FIGS. 5B-1 and 5B-2 together shows a diagrammatic representation of another servo burst pattern written according to the ~~example self servo writing (~~SSW~~) process (such as shown~~ in FIG. 4~~) according to the present invention~~. Four tracks 132 designated as~~FIG. 5B shows~~ tracks N, N+1, N+2 and N+3 are shown. The track centerlines are defined by the A, B, C and D bursts in each servo wedge. Further, the four tracks have ~~at~~ corrected centerline ~~positions~~. The "inconsequential bursts" serve to isolate adjacent tracks and prevent any correction accumulation.

The ~~servo bursts~~ A, B, C and D bursts ~~define the tracks N, N+1, N+2 and N+3 as shown, and~~ correspond to four~~different~~ track "modes." In particular, tracks N, N+1, N+2, N+3, N+4, N+5 and N+6 have track modes 7, 5, 3, 1, 7, 5 and 3, respectively~~(e.g., TM1, TM3, TM5 and TM7)~~. Each track mode indicates the sequence in which the bursts are written/trimmed, and the corresponding PES from the bursts during normal operation of the disk drive 100 is based on combinations of the burst difference values corresponding to the track mode. For example, track mode ~~TM~~1 corresponds to the burst combination PES=-(A-B)+(C-D), ~~the~~ track mode ~~TM~~3 corresponds to the burst combination PES=(A-B)+(C-D), ~~the~~ track mode ~~TM~~5 corresponds to the burst combination PES=(A-B)-(C-D), and ~~the~~ track mode ~~TM~~7 corresponds to the burst combination PES=-(A-B)-(C-D). Other track modes ~~TM~~0, ~~TM~~2, ~~TM~~4 and ~~, TM~~6 are used for two burst tracks (i.e., A, ~~and~~ B bursts or C, ~~and~~ D bursts).

In ~~this example, in~~ writing the servo bursts for track N using track mode ~~TM~~7, ~~first, all~~ the A bursts are written in a revolution of the disk 108. Then, in another revolution of the disk 108 ~~all~~ the C bursts for ~~the~~ track N are written. Then, in another revolution of the disk 108 the B bursts are written and~~wherein~~ each B burst trims the bottom edge of a corresponding A burst. The trimmed portion of the A burst, which includes the bottom edge of the A burst, is ~~(~~represented as a dashed box~~,~~ designated as "A trimmed."~~)~~. During the revolution of the disk 108 in which ~~As~~ each A burst is trimmed, the ~~instantaneous~~ PES that indicates the position of the A, B burst seam 130d ~~(PES_RRO) at that location~~ is read from the reference pattern and stored in memory~~, wherein the instantaneous PES information~~

~~indicates the position of the A,B seam 130d~~. Then, in another revolution of the disk 108 the D bursts are written and ~~wherein~~ each D burst trims a corresponding C burst. The trimmed portion of the C burst, which includes the bottom edge of the C burst, is ~~(~~represented as a dashed box~~,~~ designated as "C trimmed."~~)~~. During the revolution of the disk 108 in which ~~As~~ each C burst is trimmed, the ~~instantaneous~~ PES that indicates the position of the C, D burst seam 130e ~~(PES_RRO) at that location~~ is read from the reference pattern and -stored in memory~~, wherein the instantaneous PES information indicates the position of the C,D seam 130e~~. The recorded PES'~~-RRO value~~s are then used to determine ERC ~~correction/offset~~ values that are written into the RRO fields 133.

Referring back to~~the steps in the flowchart in~~ FIG. 4~~ for self-servo-writing burst patterns that are shown by the diagrammatic representation in FIG. 5B~~, the SSW involves~~steps in FIG. 4 refer to~~ writing/trimming the servo bursts from bottom to top, in sequence, in FIGS. 5B-1 and 5B-2. W~~In this example, w~~riting the four ~~4-~~burst servo pattern is performed in eight steps which represent the four ~~different~~ track modes. The process starts at a track mode (e.g., track mode ~~TM~~1)~~,~~ and cycles through the track modes depending on the steps~~ in the eight-step process, as shown by the example in FIG. 5B and described hereinbelow~~.

T~~o simplify understanding, t~~he steps in FIG. 4 are also shown FIGS. 5B-1 and 5B-2, from bottom to top~~ of FIG. 5B~~, in sequence. E~~, and e~~ach step is aligned with the respective burst writing/trimming operation, with further explanation provided at the bottom of FIG. 5B-2. Referring to ~~the steps in~~ FIG. 4 in conjunction with the ~~diagram in~~ FIGS. 5B-1 and

5B-2, ~~(~~starting from track N+3 at the bottom of~~-~~ FIG. 5B-2~~,~~ and moving from the bottom of FIG. 5B-2 to the top of FIG. 5B-2, from the top of FIG. 5B-2 to the bottom of FIG. 5B-1, and from the bottom of FIG. 5B-1 to the top of FIG. 5B-1~~)~~, the sequential ~~detailed~~ steps for writing the servo bursts for the four tracks N, N+1, N+2 and N+3 are as follows~~described, wherein~~:

1) The B bursts are written in a disk 108 revolution (step 400);

2) The~~n~~ D bursts are written in another disk 108 revolution (step 402);

3) The~~n~~ A bursts are written in another disk 108 revolution~~,~~ and~~wherein~~ each A burst trims a corresponding B burst~~s~~ (inconsequential burst) (step 404);

4) The~~n~~ C bursts are written in another disk 108 revolution~~,~~, ~~such that~~ each C burst trims a corresponding D burst (creating C, D burst seams 130e)~~,~~ and ~~wherein~~ the ~~instantaneous~~ PES (PESc) from the reference pattern for each C burst (and C, D burst seam) is recorded (e.g., stored in memory in the controller 136) ~~while writing each C burst~~ (step 406);

5) The~~n~~ B bursts are written in another disk 108 revolution, ~~such that~~ each B burst trims a corresponding A burst (creating A, B burst seams 130d) and~~, wherein~~ the ~~instantaneous~~ PES (PESb) from the reference pattern for each B burst (and A, B burst seam) is recorded~~stored in memory~~ ~~while writing each B burst~~ (step 408);

6) The~~n, the~~ just stored PES'~~values~~ (PESb and PESc) are used to determine an ~~correction value~~ ERC value~~,~~ and the ERC~~correction~~ value is written to the corresponding RRO field (step 410);

7) The~~n~~ D bursts are written in another disk 108 revolution and ~~such that~~ each D burst trims a corresponding C burst (inconsequential burst) (step 412);

8) The~~n~~ A bursts are written in another disk 108 revolution, ~~such that~~ each A burst trims a corresponding B burst (creating A, B burst seams 130d) and~~, wherein~~ the ~~instantaneous~~ PES (PESa) from the reference pattern for each A burst (and A, B burst seam) is recorded~~stored in memory~~ ~~while writing each A burst~~ (step 414);

9) The~~n~~ C bursts are written in another disk 108 revolution, ~~such that~~ each C burst trims a corresponding D burst (creating C, D burst seams 130e) and~~, wherein~~ the ~~instantaneous~~ PES (PESc) from the reference pattern for each C burst (and C, D burst seam) is recorded~~stored in memory~~ ~~while writing each C burst~~ (step 416);

10) The~~n, the~~ just stored PES'~~-value~~s (PESa and PESc) are used to determine an ~~correction value~~ ERC value~~,~~ and the ERC~~correction~~ value is written to the corresponding RRO field (step 418);

11) The~~n~~ B bursts are written in another disk 108 revolution and ~~such that~~ each B burst trims a corresponding~~n~~ A burst (inconsequential burst) (step 420);

12) The~~n~~ D bursts are written in another disk 108 revolution, ~~such that~~ each D burst trims a corresponding C burst (creating C, D burst seams 130e) and~~, wherein~~ the ~~instantaneous~~ PES (PESd) from the reference pattern for each D burst (and C, D burst seam) is recorded~~stored in memory~~ ~~while writing each D burst~~ (step 422);

13) The~~n~~ A bursts are written in another disk 108 revolution, ~~such that~~ each A burst trims a corresponding B burst (creating A, B burst seams 130d) and ~~, wherein~~ the ~~instantaneous~~ PES (PESa) from the reference pattern for each A burst (and A, B burst seam) is record~~stored~~ ~~in memory while writing each A burst~~ (step 424);

14) The~~n, the~~ just stored PES'~~-value~~s (PESa and PESd) are used to determine an ~~correction value~~ ERC value~~,~~ and the ERC~~correction~~ value is written to the corresponding RRO field (step 426);

15) The~~n~~ C bursts are written in another disk 108 revolution and~~such that~~ each C burst trims a corresponding D burst (inconsequential burst) (step 428);

16) The~~n~~ B bursts are written in another disk 108 revolution, ~~such that~~ each B burst trims a corresponding A burst (creating A, B burst seams 130d) and~~, wherein~~ the ~~instantaneous~~ PES (PESb) from the reference pattern for each B burst (and A, B burst seam) is record~~store~~d ~~in memory while writing each B burst~~ (step 430);

17) The~~n~~ D bursts are written in another disk 108 revolution, ~~such that~~ each D burst trims a corresponding C burst (creating C, D burst seams 130e) and~~, wherein~~ the ~~instantaneous~~ PES (PESd) from the reference pattern for each D burst (and C, D burst seam) is record~~stored in memory while writing each D burst~~ (step 432);

18) The~~n, the~~ just stored PES'~~-value~~s (PESb and PESd) are used to determine an ~~correction value~~ ERC value~~,~~ and the ERC~~correction~~ value is written to the corresponding RRO field (step 434); and so on.

The calculation of the ~~correction values~~ ERC values~~,~~ is dependent on~~of~~ the servo write technique being used. For example, if in the example of FIGS. 4, 5A-1, 5A-2, 5B-1 and 5B-2~~,~~ a one-pass trimmed process ~~is used to~~ writes the servo bursts, the ERC calculation is track mode dependent according to Table 1 below, where~~in~~ x is a positive integer:

Table 1

Track ~~Trk~~ M~~m~~ode	Track ~~data trk~~ Number~~no.~~	Servo Track ~~servo trk~~ Number~~no.~~	PES	ERC
5	4*x+0	3*x+0	(A-B)-(C-D)	-(PESa+PESd)/2
3	4*x+1	3*x+1	(A-B)+(C-D)	-(PESa+PESc)/2
1	4*x+2	3*x+2	-(A-B)+(C-D)	-(PESb+PESc)/2
7	4*x+3	3*x+2	-(A-B)-(C-D)	-(PESb+PESd)/2

In another example, if ~~an untrimmed~~ one-pass untrimmed process is used to write the servo bursts, the ERC calculation is ERC=-(PESa+PESb+PESc+PESd)/4, independent of the track mode. As those skilled in the art will recognize, similar calculations can be used for processes with multiple writes and independent trims.

As those skilled in the art will appreciate~~ with the benefit of reading this disclosure~~, ~~implicit in the above steps is that~~ the transducer 124 is moved under PES and timing control to write the various servo bursts 130c at different radial position~~locations~~ on the disk 108. Further, the transducer 124 is moved to write the RRO fields 133. In one implementation, the transducer 124 is controlled to "back-up" one and a half servo steps to write the RRO field 133 that corresponds to the track ~~write~~ centerline~~ position~~. In another implementation, if backing-up to write the RRO fields 133 ~~causes problems by~~ interrupts~~ing~~ the SSW~~the servo write process,~~ then the RRO fields 133 are written to a convenient track location as soon as the ERC values are calculated (without backing-up the transducer~~head~~ 124), and ~~then~~ in a later step (e.g., ~~in~~ a test process) the RRO fields 133 are "moved" by reading the ERC values~~correction information~~ therein and re-writing the ERC values ~~correction~~

~~information~~ at the desired track location. In accordance with another aspect of the present invention, if the micro-jog (reader-to-writer offset) profile for the transducer 124~~head~~ is determined, then the RRO correction for the read position can also be calculated.

T~~As those skilled in the art appreciate, t~~he present invention is applicable to other servo burst patterns and other burst numbers (e.g., a six~~6~~ burst system) by taking into account the servo burst relationships and how the servo bursts trim one another. The present invention is also applicable to ~~systems where there are~~ independent trim passes (e.g., the burst trim passes are separate from the burst write passes). The present invention is also applicable to servo writing ~~methods~~ that uses multiple writes, where~~in~~ e.g. the A burst is written and trimmed twice~~,~~ and ~~such that~~ the average of the A, ~~bursts and~~ B bursts is~~are~~ used. The~~at~~ mis-positioning of each servo burst is the sum of the ~~instantaneous~~ PES's due to recorded NRRO and whatever correction is performed when correcting the spirals for RRO ~~therein~~. This indicates the mis-positioning of each servo burst~~,~~ which is used to calculate the ERC~~correction~~ values. In one example, the ERC~~correction~~ values are store~~held~~ in memory until they are written to ~~disk into~~ the RRO fields 133. Typically, the ERC~~one or more revolutions of correction~~ values for one or more revolutions of the disk 108 are stored~~are held~~ in memory ~~(e.g.,~~ for the current track 132~~)~~ until the ERC values are written to ~~disk in~~ the RRO fields 133 during ~~the~~ SSW ~~process~~. Depending on how the ERC~~correction~~ values are~~is~~ used (i.e., added to, or subtracted from, the PES) by the servo control system 144 during normal operation of the disk drive 100, the ERC~~correction~~ values can have a negative or positive value. In this example, the ERC~~correction~~ values are effectively subtracted from the PES.

After ~~the~~ SSW ~~process~~, during normal operation of the disk drive 100, the transducer ~~head~~ 124 reads the servo bursts 130c in each servo sector 212 of a desired track 132. If the transducer~~head~~ 124 is placed at the burst seam 130d between the ~~bursts~~ A~~, and~~ B bursts, the ~~head~~ readback signal from the transducer 124 includes half the signal value of the A burst ~~A~~ and half the signal value of the B burst ~~B~~. If the transducer~~head~~ 124 is shifted ~~off~~ towards the A burst ~~A~~, the magnitude of the A burst ~~A~~ increases and magnitude of the B burst ~~B~~ decreases. The same applies to the ~~burst pair~~ C, D burst pair. The A, B and C, D bursts are shifted in position from each other by a fractions of the track width, such as ~~e.g.~~ 1/3 ~~of~~ track width in this example. For ~~head~~ positioning the transducer 124, ~~in one example,~~ the signal ~~value from the flux transitions in the servo bursts~~ induced to the transducer 124 from the flux transitions in the servo bursts 130c is~~are~~ ~~used in a~~ decoded~~ing process~~ by demodulating ~~the induced transducer signals~~ to form difference values (difference signals) including A-B~~,~~ and C-D phases. The t~~T~~ransducer 124 position tracking information is decoded ~~by~~ using combinations of the A-B burst phase ~~difference~~ and the C-D burst phase ~~difference~~ depending on the radial position~~(cross track) location~~ of the transducer 124 relative to the track centerline. Further, the ERC~~correction~~ values from the corresponding RRO field 133 is read by~~via~~ the transducer 124~~,~~ and combined with the burst phase difference signals~~,~~ to obtain the~~said~~ ~~position error signal (~~PES~~)~~ for ~~transducer~~ positioning the transducer 124~~by the servo system~~. The '362 patent describes combining ~~An example of using~~ ERC values with ~~in combination with~~ burst phase values~~,~~ for servo control of the transducer~~ing~~ during normal disk drive operations~~, is described in the '362 patent~~.

The PES indicates the distance between the center of the transducer ~~head~~ 124 and the centerline ~~(e.g., centerline 320b)~~ of the desired track 132. For a requested read/write operation, the PES ~~signal~~ is used by the disk drive 100 to ~~change the~~ position ~~of~~ the transducer ~~head~~ 124 ~~to one that is~~ closer to the desired (centered) position. This centering process is repeated for each successive servo sector 212 on the track 132 until the requested read/write operation is~~has been~~ performed in the appropriate data field 208~~of the disk 108~~. It should be appreciated that other schemes for storing servo information on the disk~~magnetic media~~, such as ~~schemes having said~~ A, B ~~position~~ bursts,~~;~~ ~~using~~ zones,~~;~~ constant linear density (CLD) recording, split data fields,~~;~~ and/or hybrid servo~~,~~ can also be used ~~in accordance with the present invention~~.

The present invention can be applied to SSW~~any self-servo writing system~~ where ~~some~~ temporary servo information such as the reference pattern described above is used for timing and transducer positioning to write the final servo ~~data~~ patterns. This may include printed media, partial write systems and self-propagation servo write systems, and can be applied ~~to systems~~ using multi pass writes and trims, as those skilled in the art can appreciate. Because the temporary servo information will inherently have ~~a certain amount of~~ RRO ~~in it~~, it is necessary to remove the RRO with a~~some type of~~ real-time runout correction system~~,~~ to circularize the temporary servo information before using it to write the final servo pattern~~bursts~~. The correction ~~being used~~ to cancel out the NRRO is added to whatever correction is needed to circularize the temporary servo information.

As known to those skilled in the art, in addition to the logic blocks shown in the drawings, the various methods and architectures described herein can be implemented as~~:~~ computer instructions for execution by a microprocessor, ~~as~~ ASIC ~~unit~~s, firmware, ~~as~~ logic circuits, etc.

The present invention has been described in considerable detail with reference to certain preferred versions thereof; however, other versions are possible. Therefore, the spirit and scope of the appended claims should not be limited to the description of the preferred versions contained herein.

Abstract

A disk drive ~~method and system for~~ self-servo writes~~ing~~ ~~track locations~~ on a storage ~~surface of a data~~ disk ~~of a disk drive~~. S~~S~~ervo bursts are self-written along a ~~circular~~ track using~~via~~ a transducer, ~~and~~ a ~~first~~ position error signal (PES) indicating repeatable runout due (RRO) for ~~to mis-positioning of~~ the~~said~~ ~~first~~ servo bursts is determined using a reference pattern,~~. Then,~~ an embedded runout correction (ERC) value is calculated based on the PES~~first position error signal,~~ and stored in a corresponding servo sector, and then ~~while~~ the disk drive self-writes~~ing~~ other servo burst~~track locations~~.